

RL-TR-95-42
Final Technical Report
March 1995



INDEPENDENT VERIFICATION AND VALIDATION OF THE ADVANCED PLANNING SYSTEM

CTA, INC.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE March 1995		3. REPORT TYPE AND DATES COVERED Final Mar 90 - Dec 94	
4. TITLE AND SUBTITLE INDEPENDENT VERIFICATION AND VALIDATION OF THE ADVANCED PLANNING SYSTEM				5. FUNDING NUMBERS C - F30602-90-C-0013 PE - 63617F PR - 2321 TA - 06 WU - 03	
6. AUTHOR(S) John A. Beyerle, Warren G. Hamblet, and David A. Kane					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) CTA, INC. 175 Middlesex Turnpike Bedford MA 01730				8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Rome Laboratory (C3AA) 525 Brooks Rd Griffiss AFB NY 13441-4505				10. SPONSORING/MONITORING AGENCY REPORT NUMBER RL-TR-95-42	
11. SUPPLEMENTARY NOTES Rome Laboratory Project Engineer: Kenneth B. Hawks/C3AA/(315) 330-4262					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) On 1 Mar 90, the APS IV&V program was awarded to CTA, Inc. This final report provides a summary of the tasks performed under the APS IV&V contract and documents the lessons learned from performance of the IV&V effort in an Evolutionary Acquisition/Rapid Prototyping (EA/RP) environment. It documents an alternative to IV&V derived specifically for an EA/RP development environment.					
14. SUBJECT TERMS Independent verification and validation (IV&V), Software quality assurance, Evolutionary acquisition				15. NUMBER OF PAGES 32	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL		

SUMMARY

The Independent Validation and Verification (IV&V) contract for the Advanced Planning System (APS) program represented an effort to explore alternative concepts for performance of IV&V in the Evolutionary Acquisition/Rapid Prototyping (EA/RP) environment. The EA/RP environment with its continually evolving requirements baseline and design, is fundamentally unsuited for the application of traditional IV&V concepts where the approach is predicated on one phase of the development effort completing prior to commencing the next phase.

Command and Control (C²) software has always been difficult if not impossible to develop on time and on budget. The requirements are dynamic, and the very large software systems needed take either long development cycles with a small team, or long development cycles with a large team. The only difference being in the amount of coordination and communication required. The EA approach was adopted by the Joint Logistics Commander's Panel as a solution to this problem. The APS was one of the first C² systems to implement this acquisition approach.

Specific solutions to the dynamic nature of the IV&V problem were to apply three tactics in employing the IV&V resources. Rather than attempt 100% coverage of product for each prototype released, spot samples were chosen based on critical functional factors. In order for a sampling theory to succeed, a new perspective of analysis was derived to review the software from a vertical perspective, i.e., analyze the requirements, design, and implementation of a particular function. To ensure the highest productivity, and reduce schedule time, maximum use of Computer Aided Software Engineering (CASE) tools were employed.

The implementation of this strategy allowed the IV&V contractor to focus the available resources on those areas that were most crucial to the success of the program at a given point in time. During the prototyping phase, the IV&V efforts were concentrated on new and evolving functionality. This approach allowed the IV&V contractor to maximize the effectiveness of limited resources and still provide comprehensive coverage of the APS product.

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INTRODUCTION

APPLICATION SYSTEM DESCRIPTION

The APS is an integrated, force level air battle planning system which supports personnel within the force level structure of the Theater Air Control System (TACS) to develop air battle plans and generate air tasking to achieve the objectives of the Joint Forces Air Component Commander's (JFACC) overall strategy. The force level element of the TACS is the Air Operations Center which is used by the JFACC to manage the application of combat air power. The APS provides the JFACC with the means to organize, plan, direct and coordinate organic aviation elements with those of other services and countries during joint or combined combat operations. The APS provides the JFACC with enhanced capabilities which enable the Combat Plans Division (CPD) to perform the following tasks more effectively:

- a. Coordinate air operations with higher, adjacent and support headquarters.
- b. Coordinate apportionment recommendation meetings.
- c. Determine allocations.
- d. Perform air defense and tactical air support planning.
- e. Establish and maintain planned sortie rates.
- f. Conduct mission planning.
- g. Prepare the Air Tasking Order for distribution.
- h. Receive, store and utilize intelligence information.

The APS is one of the first software only systems to obtain a formal system nomenclature as the AN/TYQ-43 V(1.0).

PROBLEM DOMAIN

The Command and Control (C²) mission area has always been characterized by the inability to define in detail the operational capabilities and functional characteristics of a system before the start of development.^{1, 2} To solve this paradox, the concept of evolutionary acquisition was introduced for the development of C² systems. Evolutionary Acquisition (EA) is defined as:

Evolutionary acquisition is an acquisition strategy which may be used to procure a system expected to evolve during development within an approved architectural framework to achieve an overall system capability. An underlying factor in evolutionary is the need to field a well-defined core capability quickly in response to a validated requirement, while planning through an incremental upgrade program to eventually enhance the system to provide the overall system capability. These increments are treated as individual acquisitions, with their scope and content

¹ "Report of the Defense Science Board Task Force on Command and Control Systems Management," July 1978, Office of the Under Secretary of Defense Research and Engineering, Washington, D.C.

² "Command and Control (C²) Systems Acquisition Study Final Report." September 1, 1982, The Armed Forces Communications and Electronic Association, Falls Church, Va.

being the result of both continuous feedback from developing and independent testing agencies and the user (operating forces), supporting organizations, and the desired application of new technology balanced against the constraints of time, requirements, and cost.¹

EA did not offer a complete solution for the development and fielding of the APS. The definition of the fieldable core, was too complex to be specified at the outset of the program, therefore the APS Program Office applied the Rapid Prototyping (RP) development approach during the core system evolution phase. A series of prototypes was developed to gain user involvement and feedback. The system core functionality was prototyped in a series of increments. Each increment demonstrated the maturation of previous capabilities while providing additional capability for user review and comment. The integration of EA and RP methodologies was a very effective approach for developing the system. However, in this dynamic and fast paced development environment, the usual methods of performing IV&V were no longer germane.

IV&V is best described as an evaluation "by an independent contractor, to insure that the software properly performs all intended functions and of equal importance that it performs no unintended functions"². In order to effectively evaluate a system, IV&V practices should "evaluate software through all phases of the life cycle: requirement definition, design, coding, test and integration. Adherence to standards, schedules, design, procedures, etc. (should) also (be) evaluated".

The IV&V effort for APS was designed to provide a comprehensive evaluation during APS development phases III, IV, and V of the software project to ensure that:

- 1)Errors are detected and corrected as early as possible in the software life cycle;
- 2)Project risk, cost and schedule effects are lessened;
- 3)Software quality and reliability are enhanced;
- 4)Management visibility into software process is improved;
- 5)Proposed changes and their consequences can be quickly assessed.

The IV&V requirements had to be satisfied even though the APS program was tasked to build and field a system more rapidly than the typical acquisition cycle provides. The methodology chosen for the development effort was the EA/RP methodology. This methodology was based upon a top level set of system requirements being defined or hypothesized, which are then continually refined in an iterative manner through a series of incremental software prototypes

¹ "Evolutionary Acquisition: An Alternative Strategy for Acquiring Command and Control (C²) Systems," March 1987, The Defense Systems Management College, Fort Belvoir, VA

² USAF Space Division "Management Guide for IV&V" August 1980

that let the user community actually use the system and provide feedback to the developer during the development cycle. The EA/RP approach represents a marked departure from the classical systems engineering or traditional "waterfall" development model. (See Figure 1.) The major departure involved with the EA/RP methodology, is that the system and its requirements evolve during development, vice deriving and defining the requirements as a separate activity presaging the rest of the development¹ as is the norm with a traditional development effort. The EA/RP development model more closely follows the spiral development model of Dr. Barry Boehm. (See Figure 2.)

The result of this EA/RP approach on APS, is that the detailed requirements and design actually developed at the same pace as the deliverable software. This EA/RP approach therefore dictated that alternative technologies and/or methodologies for the performance of the IV&V effort must be developed as the classical IV&V techniques/methodologies are associated with a development effort following the traditional model.

The IV&V role is typically concerned with answering the following two questions "Are we building the product right?" (Verification), and "Are we building the right product?"

(Validation)². Typically, much of the effort is spent reviewing the requirements for completeness, consistency, testability, etc.. Then the requirements are compared with the top level and detailed designs. As the code comes into being, it is then compared to the design and the requirements. After the evaluation, the code is tested against the requirements and engineering design. The labor and manpower required to perform this task on the APS following accepted IV&V methodology was determined to exceed the cost of the system development.

As a result of this analysis, three approaches were selected to solve this dilemma:

- 1) Focus on critical areas of the code, and apply sampling theory to verify the product. This concept became known as "Spotlighting" to the APS development team, as it provided a means to focus the available resources on critical areas.
- 2) Explore the application of Computer Aided Software Engineering (CASE) tools and usage of a modern Software Engineering Environment (SEE). The application of reverse engineering technology offered leverage for both the development team and IV&V contractor to improve productivity.
- 3) Concentrate analysis activities on functional problems. This concept was termed "Veracity" because the goal was to determine the truthfulness, completeness, accuracy, precision, fidelity, and integrity of an algorithm across the executing units and databases utilized.

¹Hawks, Kenneth B, New Methodologies for Verification and Validation in Evolutionary Acquisition, AIAA-91-3820-CP, p. 780.

² Barry, Boehm, Software Engineering Economics, Prentice-Hall, 1981, p.37.

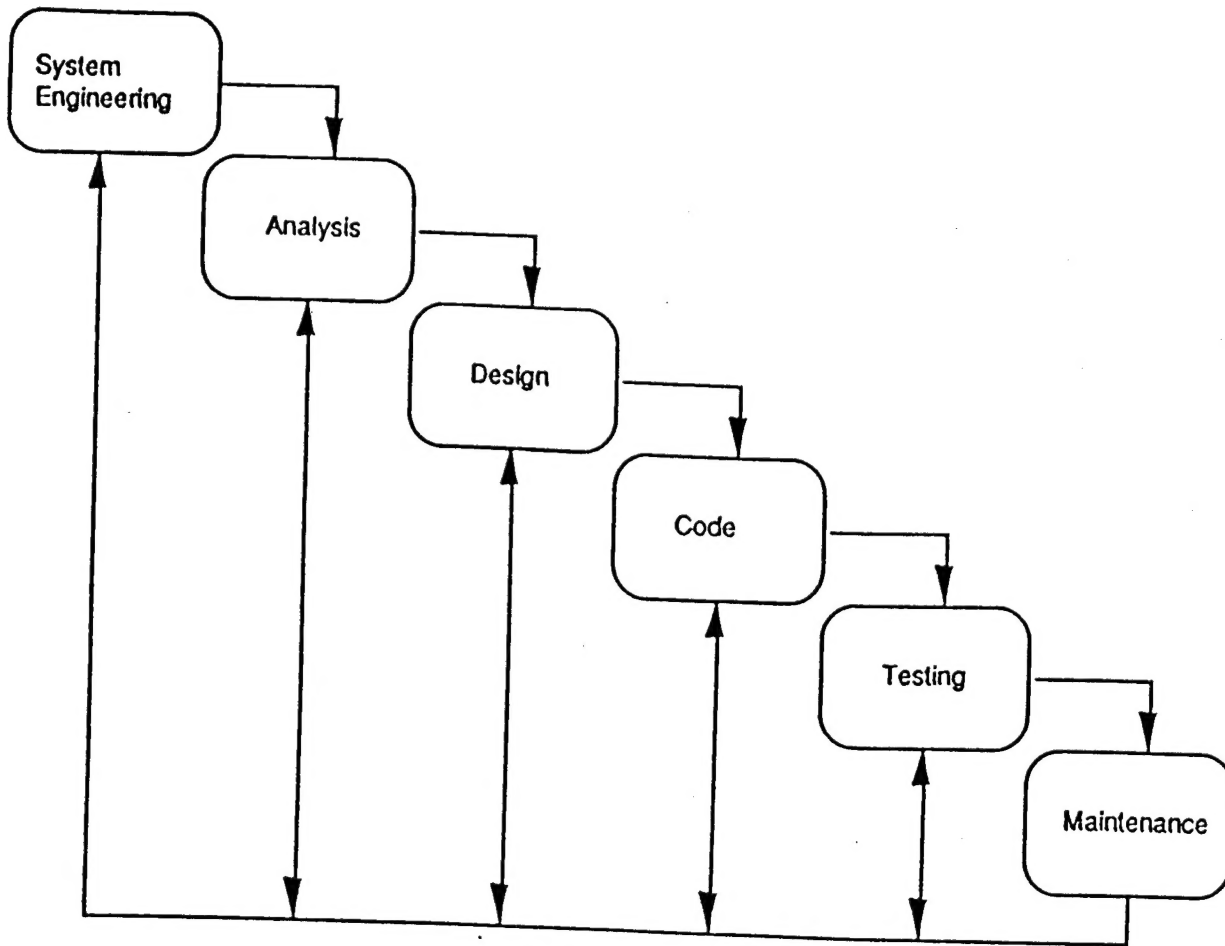


Figure 1 - Traditonal (Waterfall) Development Model

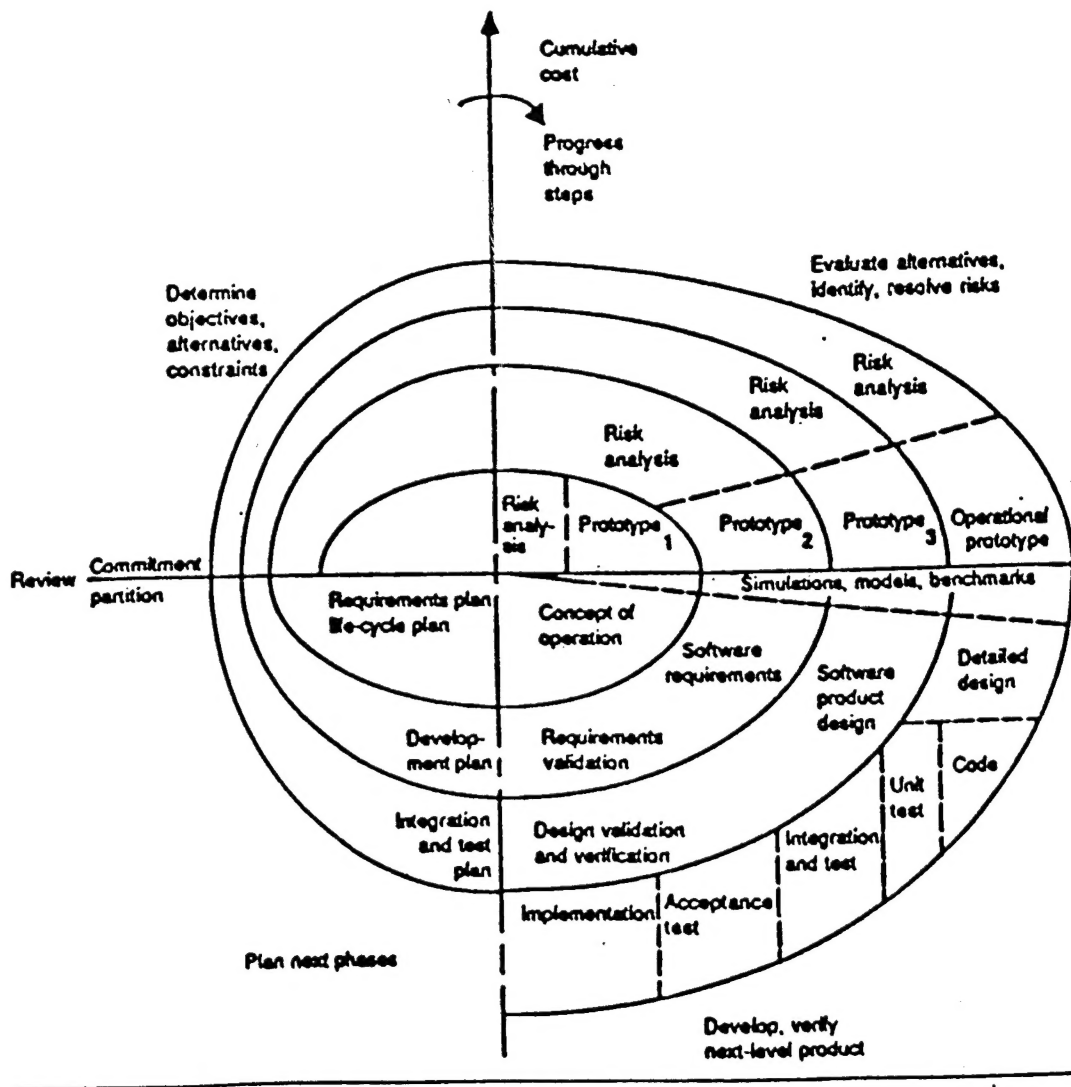


Figure 2 - Spiral Development Model¹

¹ "A Spiral Model of Software Development and Enhancement", May 1988, IEEE COMPUTER, IEEE Headquarters, 345 E. 47th Street, New York, NY 10017.

OVERALL IV&V STRATEGY

Technical Approach

The APS IV&V problem is multi-dimensional, and extremely complex. There were numerous unique aspects of the APS IV&V concept. Due to the dynamic nature of the system development schedule, several factors influenced the IV&V approach. Timeliness was critical. Finding errors and getting them fixed could not be a six month long process, when a new prototype was being introduced at six month intervals. A balance between and among resources was paramount since not every function point could be evaluated in-depth for each release. This led to one of the primary concepts of the APS IV&V, which was the emphasis of analyzing critical areas, vice a comprehensive review of all requirements implementation. Once chosen for evaluation, an area under development was examined in depth.

The IV&V team was small, thus skill application and efficient use of the individual skills was very important. When an error was found by either the software development or CASE tools, the first task was to validate that the answer supplied by the tool was correct. In a similar manner, Commercial-off-the-shelf, and "netware" integrated into the program was also evaluated for errors. In every activity, the contribution to the APS system also had to be kept in mind. An important element was to identify the source and type of error. Errors could be caused by faulty design; faulty algorithmic implementation; faulty database design, consistency, or erroneous data; or inappropriate operator actions. Likewise the source of errors could also be a result of problems in the documentation, designs, implementation, code, or usage. (See Figure 3.)

The fundamental strategy was to Evaluate - Assess - Recommend. This paradigm was the key element in the accomplishment of all tasks. The evaluation was tailored to the particular function point being reviewed. The assessment was scoped to fit the desired end goal of depth and detail. One of the cardinal ground rules was that every evaluation have a recommended solution. In this manner the evaluation process contributed to the development process by suggesting better solutions as well as finding weakness in the developing product. All too often IV&V efforts result in the IV&V team just finding problems without having the responsibility to assess the problem and propose a solution. This results in an adversarial relationship between developer and IV&V teams, and in extreme inefficiency for the development team, as effort has to be wasted to validate the problem, measure its scope, figure out a solution, and finally implement the solution. While the development team is not obligated to implement the solution proposed by the IV&V contractor, the evaluate - assess - recommend approach assured that the entire problem was understood, and that a solution did exist.

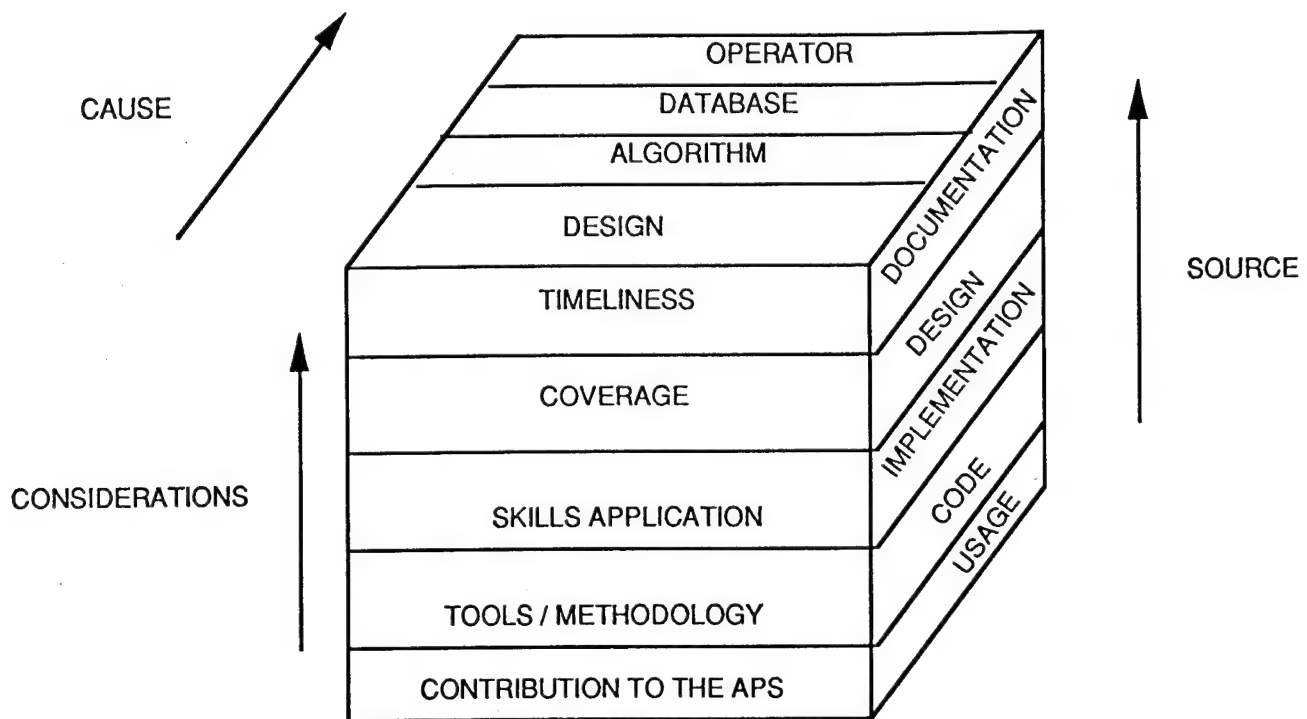


Figure 3 - APS IV&V Model is multi-dimensional

The Verification and Validation areas were established as follows to support the new IV&V paradigm in the EA/RP environment.

Verification was formally scoped as five task areas:

- Testing oversight and conduct.
- Database content and review.
- Interface review.
- Specification review.
- Audit support for Physical Configuration Audit.

While these task assignments are similar to the traditional IV&V efforts, how they were executed in the EA/RP environment was radically different. Testing oversight, database content, interface review, and specification review were performed on a function point basis using sampling techniques. As a functional evaluation was performed, the requirements through implementation documents were reviewed, and the quality of the function measured. The reverse engineering capabilities of the SEE tool set provided the capability to audit the C and Ada code for PCA almost entirely via computer.

Validation was formally scoped as five tasks:

- Formal Qualification Testing - User Evaluations.
- Requirements Satisfaction.
- Concepts of Operations Implementation
- User Expectations
- Audit support for Functional Configuration Audit.

Validation was performed by the user community until the acceptance of the common core release of the APS. The IV&V contractor performed a vital role between the development team and user by recording and analyzing the comments received. Upon fielding of the system core, the IV&V contractor became prime for the Validation tasks

Management

To address the needs of performing IV&V in an EA/RP environment, there were certain limitations/constraints that needed to be acknowledged and appropriate measures defined to deal with them. The primary limitation(s) were the prototyping schedule and the continually evolving requirements baseline as the prototypes incorporated increasing amounts of functionality. The typical IV&V methodology which is designed to support a classical development program (i.e. Boehms' waterfall model) were clearly inappropriate in the context of the EA/RP environment.

To respond to these issues a specific blend of personnel were defined and the concepts of "Spotlighting" and "Veracity" were evolved to guide the staff in performance of the IV&V task.

The contract itself was structured to allow control of the IV&V effort, with a maximum of flexibility for the contractor. Overall, three levels of reporting structure were implemented. At the top was the program level IV&V Program Plan. This plan outlined the resources available, the management structure of the IV&V team, and the broad guidance for the approach. The Program Plan was revised quarterly to reflect near term goals and objectives, and to identify specific resources to be applied to specific areas, such as testing or auditing. The monthly status reports provided a means to fine tune the application of resources, and communicate the status of tasks in process.

Feedback loops for the IV&V process were provided in the technical problem reporting system, trip and technical reporting, and in appendixes to the monthly reports. As technical problems were revealed, an evaluation report was rendered electronically and provided to the APS program office. The program office then reviewed the report and electronically forwarded it to the contract team for action as appropriate. As individual areas were investigated, technical reports were rendered electronically immediately. This approach assured that overall findings could be reviewed and forwarded to the contract team in a timely manner. If travel was required to review a developing function, the overall report of the investigation was contained in the trip report. Several tasks were long term in nature, i.e., oversight of the configuration management system, and these tasks were statused in the monthly reports. Specific problems found in long term tasks were documented in technical reports or evaluation reports as applicable.

This management framework provided the visibility for the APS Program Office to stay abreast of and control the IV&V team, while also getting the output of the IV&V tasks in a timely manner. This approach minimized the cost of report preparation, maximized customer visibility, and ensured timely reporting of problem areas.

Personnel

Reflecting the dynamics of the EA/RP environment, a crucial component to the success of the program was the composition of the IV&V staff. The APS IV&V effort required a small group of engineers with a diverse background to successfully execute the contract as envisioned. The personnel required a combination of skills that typically would only be found in a larger organization; the following areas of expertise were defined at the outset of the contract as the mandatory skill set for the team to possess and served as the basis for all staffing decisions throughout the entire period of performance. The skills/areas of expertise were:

- Extensive background in Command, Control, Communications (C3) decision aids;
- Software Configuration Management;
- Experience in the following programming languages: C, SQL, and Ada;
- Software/system level testing experience;
- Experience in the use of modern Software Engineering Environments;
- Experienced data base designer/data analyst, and;
- Experienced system engineer.

CTA management was extremely successful in finding and retaining staff with the appropriate qualifications throughout the life of the contract. Key personnel remained with the contract from

the initial startup through the eventual ramp down after the decision was made to not extend the period of performance as planned. Without the ability to attract and retain personnel for the length of the program, the knowledge base and expertise required to rapidly assess changes and their impact upon APS would have significantly diminished the ability to execute the IV&V concept as envisioned by the Government and CTA.

IMPLEMENTATION

A series of technical exchange meetings were held between the program office team and the IV&V team to establish how the IV&V strategy would be applied in detail. This "technical action group" defined how the concepts of "veracity", "spotlighting", and the CASE tools would be applied.

Veracity

The veracity concept was constructed to ensure that the fundamental building blocks of the planning system reflected reality and were accurate. The APS IV&V was implemented using a sampling technique whereby key elements of the system were subjected to a thorough and in-depth review from a vertical perspective vice the classical horizontal perspective. In a traditional program, the requirements baseline would be established and the IV&V contractor would perform a thorough review of that baseline. Next a design would be developed to implement the requirements, and finally code would be produced which implemented the design. This review process essentially looks at the system horizontally over time. At each stage, the review process goes back only to the prior stage, the entire system is not examined at once. By adopting a vertical perspective and implementing sampling technique, key portions of the system are reviewed in their entirety (requirements, design, implementation) at once. Based upon the results of the various samples, problem areas can be identified quickly and specific problem areas can be tracked/managed via trend analysis.

Veracity is both an analysis perspective and an analysis criteria. It can be the framework for gaining a perspective on an algorithm or contiguous component of the software. The dictionary¹ and thesaurus² lists the following as components of veracity:

- Truthfulness - of logic.
- Accuracy - of calculation, of results,
- Precision - of data, results,
- Faithfulness - of implementation of requirements; design,
- Fidelity - accuracy of description,
- Integrity - cohesiveness with related algorithms, autonomy of self,

Thus when a function is viewed from the standpoint of veracity, a requirement is reviewed, compared to design, the design compared to the code, testing results evaluated, and the interaction of the function with related functions are also reviewed. By reviewing the various levels of abstraction of the software, a perspective of implementation of a particular algorithm is gained and a quality assessment made.

The veracity concept worked extremely well in the APS environment where the essential structures of the system models could be captured and analyzed via the spotlight technique. In

¹ "Webster's New World Dictionary", Third College Edition, Simon & Schuster, 1988

² "Roget's College Thesaurus", 43rd Edition, Signet Books, 1962

this case the fundamental underpinning of the system models were documented in the database structure, before code had been developed to access/manipulate the database tables. As a case in point, the targeting model and the various relationships were defined/refined extensively prior to any code being written to implement the actual target planning logic.

Once selected for evaluation, the depth and detail of verification was established. Evaluation criteria consisted of data consistency across all units of the program, completeness of the models that were being developed and then recording these results both on a point in time sample as well as tracking trends in a particular compilation unit over time. The concept of veracity allowed IV&V personnel the latitude to track the interactions of a function among and within related functions, while providing boundary constraints.

Spotlighting

Spotlighting is an approach to accomplishing IV&V using sampling techniques. In the context of APS it can be thought of as shining a strobe light into a particular area of concern at some point in the program and evaluating the completeness of the design, the accuracy of the implementation, etc.. Samples were based upon the criticality of new functionality, volume of user feedback, complexity of the function, and gut feel of the program office personnel. Since functionality was either being developed from scratch or being constantly refined, any evaluation was good for only a very brief period of time. Thus the perception of the function being in the spotlight for a few moments, then fading into the background.

The selections picked for sampling, were chosen by conventional means. New functionality that the users felt was important; previous functionality up dated because of user feedback; and functions not normally visible to the user, but critical to the performance of the system.

Spotlighting allowed the IV&V Program Manager the flexibility to coordinate the IV&V staff efforts with the Government schedule and focus the available resources on those areas that were crucial to the success of the program. Spotlighting can also be applied as a "tiger team" concept where the intent was to go in, thoroughly examine a particular area and then move on to the next area deemed crucial. There were times when this ability to "hit an' git" proved very useful for committing to program milestones.

CASE Tool Application

A necessary component of the IV&V methodology was to leverage the investment and usage of automated tools to aid both the development and IV&V teams. This was particularly important given the small number of personnel assigned to the program and the requirement for a complete new release every three to six months during the prototyping phase of the program. A number of SEE's were investigated which were available in the late 1990 time frame. The requirements were that the SEE chosen had to be available on both the DECstation and Sun SPARCstation environment, and provide tools that would provide assistance in the design, test, documentation, and configuration management areas. A critical requirement was the ability to automatically support reverse engineering of existing code.

The program did not have the schedule time nor manpower to correlate the documentation with the actual code. A significant amount of code was acquired from existing sources. Internal Research and Development (IR&D), public domain software from the Internet, commercial software, legacy and existing software, all were incorporated into the APS. The SEE tools also had to increase engineer productivity, and result in a product that was of higher quality and reliability, and maintainable when turned over to the Air Force at the conclusion of the program.

The IV&V contractor evaluated a number of CASE tools and recommended that a modern SEE based on the Cadre Teamwork CASE tool be adopted by the APS program for usage both by the developer and the IV&V staff. This CASE tool allowed maximum leverage of the available personnel by supporting a variety of program activities (design, coding, testing, analysis, and document generation) within a single environment that can be shared by all personnel. The Cadre product provided extensive design and coding support as well as a reverse engineering tool that allowed structure charts/graphs to be constructed for a given release for both the Ada and C code. It also provided the ability to generate the DoD standard 2167A documentation that was required for APS. The reverse engineering capability provide a quick view into what is, while the requirements and design documents provided a view what was intended. A quick comparison of the two revealed deviations that could be evaluated.

The combination of these techniques/methodologies allowed the IV&V team to provide real time feedback to the Government with respect to the quality and completeness of the APS system as it was evolving. Without these techniques and methodologies, CTA would have been analyzing requirements, design, and code baselines that were significantly out of date with respect to the current baseline and would not have been as responsive as required to support the dynamics of an EA/RP environment.

CodeCenter from Centerline software provided extensive testing capabilities for the portion of APS developed in C. In the language context, it provided similar checking to the capabilities of an Ada compiler. It provided a useful tool in the context of FCA/PCA to examine the code for compliance with the appropriate coding standards and correctness automatically. The audit of the code to its documentation, was also done automatically. The use of the SEE made it possible to perform a FCA and PCA with each major release of the APS.

The adoption of these products represented a significant cost to the Government as the Government acquired the required licenses for both IV&V/Government use and the development team. This cost was off-set by a higher quality product and increased productivity. However, the results that were achieved using the tools did not realize the full potential of the tool suite. This was due to a number of factors, the most significant one being that the tools were not used in the forward direction, i.e., during the design phase of a particular function, thus the capability of the tools to evaluate the designs prior to coding was lost. In subsequent development efforts, a SEE, such as that selected for APS, should be defined prior to the start of the detailed design process, the entire development team needs to have access to it, and a commitment must be in place to use it to support the entire development process.

Configuration Management/Change Tracking in EA/RP Environment

One of the key tasks in a EA/RP environment is maintaining a working control of the various baselines, in particular the user requirements and code baselines. In point of fact, given the highly iterative nature of an EA/RP environment controlling the requirements baseline is even more crucial than in a classical development environment as the tendency towards requirement creep is heightened due to the constant interaction between the developers and the users. This environment tends to enhance the natural desire to provide the user with changes and/or modifications in a rapid manner without always taking the time to evaluate the overall impact on cost and/or schedule constraints. In recognition of this tendency, the Government charged the IV&V contractor with the responsibility for both administering the Program level Change Management and Tracking (CMAT) component of the APS prototype and Evaluation Reporting System and monitoring and assessing the developer's Configuration Management Practices.

This approach provided multiple benefits to the APS program. First and foremost, the Government maintained the top level set of system requirements as documented in CMAT throughout the life of the program. It also allowed the developer to focus on implementing a set of Configuration Management practices for the code that were applicable for the APS environment. The use of the SEE allowed the development team more latitude in the degree of discipline required in the configuration management (CM) philosophy applied.

User Evaluations often generated over 300 comments, thus the APS Program Office needed a method for organizing user comments, and product improvement requests. To support the volume of comments generated by the evaluators a reliable, flexible, and user friendly tool that would allow the incorporation of this information into a single automated system was dictated. The system also needed to incorporate the previous unresolved user comments into the "next phase" of APS while providing identical content between the Program Office and the Software Development Team.

The APS Program Office also realized that a need existed for a system that would allow for the recording of Software Change Requests and Preplanned Product Improvement (P3I) requests generated during the Theater Tailoring portion of APS. After several COTS products were reviewed and found to be inadequate, the CMAT system was developed to assist the APS Program Office and the Software Development Team in the management of the APS user comments, Software Change Requests and P3I requests.

During the EA/RP phases of the APS contract, the APS Program Office used the CMAT system to record all APS comments from the user community. The user comments were then disseminated by the APS Program Office and those deemed appropriate were forwarded to the software developers for inclusion into future releases of APS. The APS Program Office required a system that would be flexible enough to allow recording of user comments, bug reports and future enhancements, while providing a quick turn around from the "users" to the developers. When APS migrated into a more classical software development effort during the fielding and maintenance phases where stricter configuration management practices were

required, CMAT was used to record SCRs, corrective software actions and user desired enhancements (i.e. P3I items).

APS CMAT system consists of two subsystems. The first of these was developed by CTA Incorporated for the APS Program Office's use and includes the programs, forms, tables and procedures required by the Government to track and maintain the top level programmatic baseline. The second CMAT subsystem was developed by Unisys for use by their development personnel.

Within CMAT at the Program Office, SCRs are tracked and serve as input to CMAT at the developer's site. Within CMAT at Unisys, the SCR becomes a software problem report (SPR) and is worked by the development team.

As the CMAT Administrator CTA also generated all CMAT reports. These reports were required for all informal and formal reviews. Formal reviews occurred at the RL Software Change Review Board (RL SCRIB) which included members of the APS Program Office and the CTA IV&V team. The second formal review occurred at the APS Software Change Review Board (APS SCRIB) which included members of the APS Program Office, the developer's team and CTA for administration and support.

The IV&V team was involved in the review of the open SCRs to determine:

- (1) The scope and nature of the SCR
- (2) Possible SCR duplication
- (3) Possible consolidation of SCR with others
- (4) Clarity of SCR
- (5) What is the SCR assessment? (IN SCOPE, OUT OF SCOPE)
- (6) What is the SCR disposition? (P3I, CORE, THEATER)
- (7) What is the appropriate STATUS for the SCR?
- (8) Does SCR need formal review by the RL SCRIB?

SCRs and User comments were reviewed, subjected to formal configuration control boards, and upon implementation into the APS, were tested for closure. When a new version of the APS was released, the IV&V team would verify the list of SCRs reported as corrected in the developers Version Description Document (VDD) against the CMAT status. CTA then provided the SCR list to the test team members (CTA and Government) to verify that the change(s) as implemented corrected the problem described. This was done using the SEE.

The process employed on APS provided the Government and the IV&V effort valuable insight and a high degree of control over the change process during the APS development. The one area where significant improvement could be achieved in the future is in a consolidated Change Request/Problem report database that is used by the program team (Government, IV&V, and developer) staff. Significant amounts of time were required with each release to cross reference from the developers identification system to the Governments system. This was in addition to the manual coordination required after each change control board when CTA would update the Government database and then have to perform an database export and ship the database to the

developer for them to reload into their system. This process inevitably led to discrepancies in the contents between the two databases as the developers implementation was also evolving.

Testing

Testing was a key component in the development of the IV&V program. One of the key concepts of the EA/RP process is the "build-a-little, test-a-little, field-a-little" philosophy. This philosophy, while essential to developing in an EA/RP environment, does introduce some risk. The methodology chosen to mitigate this risk from the IV&V perspective was selective in-depth testing of key functional threads identified as part of the "Spotlighting" process.

In a classical acquisition, the IV&V program begins with a System Specification from which a Requirements Traceability Matrix is built. These requirements are then flowed down to the Software Requirements Specification (SRS) and Software Design Documents (SDD); then these documents are used by the IV&V contractor to analyze the developed product. During code and implementation, many issues arise and due to schedule pressures complete documentation rarely takes place. The EA/RP environment tends to compound the deviation between the "build to" documentation as compared to the "as built" system. The application of reverse engineering tools allowed the rapid updating of the "build to" documents, thus ensuring that the specification represented the actual code.

To reflect the reality of the EA/RP approach, the testing philosophy employed consisted of two elements. The first element was identifying the key functional threads that were new or significantly modified in each prototype and consequently required "spotlighting" as part of the engineering test process. The second element in the test program was support to the FQT Program between the Government and the developer.

Spotlight testing was designed to ensure that each function was complete enough and robust enough to ensure a valid evaluation by the users during the user evaluation portion of the prototype schedule. This testing was typically very intense from a schedule perspective as the candidate code for the prototype was typically not available until 5 to 7 days prior to the evaluation session. This typically allowed a maximum of 3 days for the spotlight effort to test and report problems so that a correction could be incorporated by the developer prior to the first day of the evaluation session. After an evaluation the functions were tested from an engineering perspective for accuracy and stability.

The IV&V testing of APS was based upon both "black box" and "white box" testing concepts. The white box testing strategy resulted in deriving "operationally based" test scenarios to examine the functionality of the system from a real world user perspective. White box tests were derived for crucial functional strings where it was imperative to determine the veracity of the algorithms and their implementation.

A key element of the "black box" approach to validating the APS software was the incorporation of "operational test" strategies during the early stages of APS development. Operationally based test scenarios were devised early in the IV&V program and were performed as part of the Functional Prototype tests. These test scenarios were constructed around "real

world" scenarios, thereby ensuring that realistic data in terms of content and quantity was employed. This data included realistic forces, threats, system parametrics (aircraft, missiles, radar, radios, etc.). The test scenario was constructed to ensure that all United States Message Text Format (USMTF) mission types that APS was required to support would be constructed and output in the Air Tasking Order (ATO) so that the content and format of the ATO could be validated. The scenario(s) were designed as an end to end test (i.e., from receipt of a Target Nomination List (TNL) to the ATO output) of the APS software.

A major issue associated with this operational testing was assuring that the system was stressed with data and functional loads which accurately reflected the loads that could be expected by the fielded version(s) of APS. Examples of where problems were identified by the operational test were the ACC version in which the user interface supported the display of approximately 4000 separate entries for Standard Configuration Loads (SCLs), where the operational requirement (and actual data base) consisted of over 5000 entries. Attempting to retrieve and display SCL data with a data set of this size resulted in the APS User Interface application crashing, thereby preventing the users from accomplishing their planning task. This problem was discovered during the ACC test and was subsequently corrected in the next formal release. This example highlights the importance of testing with "real world" data as this function had always performed satisfactorily during DT&E levels of testing with "test data" and limited quantities populated in the data base.

In order to assure ATO message compliance for missions which are linked such as the set of USMTF (REFUEL, 7REFUEL, and EC), the operational test was developed so that realistic support mission requests/requirements were created and were planned from the appropriate APS support screen. The operational test also checked the interrelationships between missions as they appeared on the support work screens assuring that as missions were created or deleted that the support screens and requirements were updated properly. In particular that all missions that generated support requests were displayed on the appropriate (Tanker, EC) screen and also if missions were deleted that had support requests associated with them that the resources were returned to the queue to be reused.

The operational test was exercised as an end to end test from the input of a TNL to the output of the finished ATO. After the end to end test execution the individual message set items contained within the ATO were traced to their origins such as target locations in the TGTLOC set of the ATO and were in fact the Desired Mean Point of Impact (DMPI) found in the original source TNL. Each mission was traced to assure accuracy of both pass through data and system generated data (call signs were for the proper day, IFF/SIF codes were not duplicated etc.)

The IV&V test approach also recognized the fact that to check the veracity of the code, specific algorithms needed an in-depth examination to verify that the implementation was correct and reflected truth. These areas were tested using white box techniques. Specific threads that could be identified as crucial to the planning process were identified.

The examination of the refueling models consisted of capturing the design for a release into the Cadre Teamwork environment via the reverse engineering tool or by analysis of the code and manually entering the data. The analysis tools provided by Cadre were then executed to check

consistency of the design and interfaces. Specific test drivers were also prepared to execute selected modules. Analysis of the design showed that the basic design was extremely limited with regards to the refueling scenarios supported and required additional work to meet "real world" operational requirements. A number of discrepancies between the various code components were also discovered as a result of this process. The most serious from a planning perspective was that various developers implemented their portion of the code using different units of measure internally. Therefore while data could be passed back and forth between the various modules, the final result was that the computations for determining if an aircraft required refueling, how long it would take to perform the refueling, and the amount of fuel onboard the tanker were not in agreement. Among the various assumption in use were that fuel was being tracked either in pounds, hundreds of pounds, or thousands of pounds. This resulted in all missions that planned refueling to have incorrect schedules generated for the amount of fuel required, and the time to accomplish a refueling. These findings were documented in a series of reports to the Government and as SCRs which resulted in a much improved set of refueling algorithms by the time the program reached Phase V.

The second element of the test program was IV&V support to the formal test program between the Government and the developer. The IV&V contractor and the Government were the responsible agency responsible for the acceptance of the final product. The development team was not provided manpower to perform this testing. Rather than have two testing cycles in series, the APS program office decided to eliminate the contractor's testing at the system level, and to ensure a quality product, assumed the responsibility of conducting the FQT. This provided an independent evaluation of the release and afforded the program office a hands on feel for the product.

FQT for the APS program also consisted of a number of other differences in addition to the Government being the responsible agency. Typically FQT is conducted at the developer's site, the software accepted by the Government and then installed at operational sites by the Government with support on a "as-needed" basis by the developer. Reflecting the high user involvement in the APS program the first portion of the FQT was conducted at the developer's site, and after verifying the release, the FQT team (Government, developer, and CTA) traveled on-site and installed the system. The FQT was then re-run as part of the installation and training activity to ensure that the user's requirements were met and that the system operated in the real world conditions present at the operational sites. These additional tests were used to validate the FQT tests and scenarios. Some errors were encountered during these additional FQT tests. The majority of these errors were a result of the different hardware and software configurations which existed at the operational sites and which could not have been replicated at either the developer's facility or the APS Integration Lab at Rome Laboratory.

As part of the IV&V responsibility for FQT support, CTA developed and supplied the test scenario and accompanying database used to support the qualification test activities. This effort was initiated by CTA and completed in conjunction with the Government and the developer. This database then served as the baseline for all subsequent formal test activities on the APS program. This database was built based upon the real world conditions experienced during Desert Storm. This was an important step in convincing the user to accept APS, in that the

system was tested and qualified with real world data instead of allowing a tailored database be supplied by the developer that was applicable only for a qualification testing environment.

The functional stress of the system could not be fully tested during the testing at Rome Laboratory and the developers facility due to lack of the appropriate hardware suite. As a result engineering testing in a full operational configuration did not occur until the first installation at a user site to support a live exercise.

CTA engineers also served as member of the Government test team to witness and in selected cases actually execute the qualification test procedures. CTA was also responsible for monitoring the introduction of new software builds during the test cycle, (as well as conduct the regression test on each new build) as the typical test cycle resulted in 4 to 5 builds of the APS code prior to establishing a baseline that was capable of completing the qualification test.

The FQT process for APS was conducted in a manner significantly different from FQT under a traditional acquisition program. The IV&V contractor and the Government played integral roles in defining the tests, preparing the test data, and in some cases actually conducting the test. The process was also extended by requiring that the FQT not be considered complete until after the software had been installed and tested at the operational site(s).

FCA/PCA

The FCA is an audit to determine that the formal test conducted and the results of it are satisfactory to show that the system has met its qualification requirements. As part of the FCA process, CTA reviewed the developer test procedures for completeness (all requirements tested) and thoroughness (adequate test conditions to verify the requirement).

PCA is a physical audit that examines the actual code baseline used in the conduct of the test to verify that it complies with the documentation. A PCA is typically a time consuming process that for a program the size of APS would require 4 to 5 engineers a period of 2 to 3 weeks using the standard methodology of manually inspecting the code listings and comparing it to the documentation. The APS schedule requirements typically allowed one week for conduct of the FCA and PCA with a total team of 3 engineers.

In a classical software acquisition environment, the FCA and PCA typically are scheduled to occur 90 to 120 days after the conclusion of FQT. This allows time for preparation and submittal of the test report by the developer, and time (typically 30 days) for the Government to review and prepare. The typical schedule for APS required that the software be accepted by the Government and installed at the sites within 30 days from the conclusion of the FQT for each baseline release after the conclusion of the prototyping stage of the program. At the conclusion of each test the FCA/PCA was held to accept the baseline for subsequent installation at user sites. A total of three FQTs/ FCA/PCAs were conducted during the APS contract. These occurred as follows; July through August 1992 (the first formal Air Combat Command (ACC) version of APS), April through July of 1993 for the USAFE/NATO version, and October through November of 1993 for the consolidated CTAPS program baseline.

The requirement to support the users' schedule did not allow the accepted process and time line associated with a classical software acquisition for the conduct of the audits. Not only was schedule time a concern, but the resources to perform a manual audit of the code were not available. This problem was recognized early in the program and was a key element when the assessment to choose a modern SEE was performed and the assessment of configuration management practices was performed. Part of the evaluation criteria for both the SEE and CM required that the products and procedures selected had to support capturing the required data and automating the audit process to support the installation schedule required to support the user community.

To support the schedule requirements, particularly in the PCA, which is the most resource consuming, the process of the physical code inspection was automated using the tools provided as part of the SEE. This process worked particularly well with the ability to display requirements, design, and code on a screen together to compare then against each other. The SEE also provided tools to perform audits on the code for items such as variables declared but never used or not initialized.

Data Validation/Integrity

In discussing APS, the concept of veracity and the issues of data validity and database design are inexorably linked. This linkage occurred as a result of the development methodology and the developers attempt to implement functions prior to fully understanding the area and having a complete set of requirements defined. It therefore became crucial that the underlying data model be complete, flexible and reflect the needs of the algorithms supported. There were two important considerations in this area, the first was that the data representation internally and the final ATO product had to be compliant with the USMTF standards, and the second factor was the design of the database and the potential for problems both with data integrity and data base performance adversely impacting overall system performance.

The area that represented the highest risk to the APS program from the IV&V perspective was the methodology and design of the database that was being employed by the development contractor when CTA came on board. The approach in use by the developer was to start with a simple model and to continually add tables and/or define new relationships as the user pointed out problems/issues at the evaluation sessions. While this approach is adequate in a small system, when the volume of data that is required in APS, and the complexity of the relationships required to define the Air Battle Plan (ABP) are considered, this methodology poses significant risks to the Government. In particular it would result in a system with the same data represented in multiple places, and lead to a corresponding increase in complexity of the queries required to keep all the data sets synchronized. This ultimately would impact the system in two areas; the ability of the Air Force to maintain the system would be curtailed and system performance would be degraded.

While the developer team had personnel well versed in data base design methodology there was little or no domain expertise available to the database designers to ensure that the model being developed was complete or accurately reflected the true relationships required to capture the data

required for the ABP, and then convert it into the format in which it is disseminated, namely the Air Tasking Order (ATO).

With the concurrence of the Government, CTA provided an extensive review and design suggestions for portions of the data model in those areas where CTA staff possessed extensive domain expertise. In particular, the targeting model, the refueling model, and the packaging model were singled out via the spotlight methodology as areas that were of high risk and required extensive investigation. The specific criteria was that these models were the most crucial to the success of the system and were also the most complicated in terms of the data required to define the model as well as the relationships that had to be defined and understood by the developer between the data within each model and the relationships between the individual models.

The second area of concern throughout the APS program has been the adequate specification of external data sources to populate the APS database to support both the initial installation in a specific theater of operations and subsequently appropriate sources for the daily situation updates required to support the daily planning cycle.

The developer assumed that they would be provided electronic sources to interface with and initially made little provision for allowing setup data to be input manually. The key element here in the opinion of CTA was the lack of domain expertise possessed by the development team. The developers understood the volume of data that APS would require prior to initiating a planning cycle but could not appreciate the fact that electronic feeds were not available or that significant portions of the data did not even exist electronically. It took repeated design reviews and meetings to convince the developer that the majority of the data they were requesting either did not exist in electronic format or would not be available to the AOC in the format that APS required. As a result the initial design to support data input to APS was not designed at the same time as the rest of the database. This led to a number of discrepancies such as user supplied data not being stored in the data base for later use and significant discrepancies between what the User Interface allowed as legal input (format, length, restricted characters), what the data base allowed, and what the standards (i.e. USMTF) specified as legal formats. This analysis was an ongoing task through the M_AB baselines as the developer continually refined the process based upon IV&V testing results and feedback from the users. In the current version of APS (C_AD), the majority of the problems associated with the initial load of APS have been corrected. The User Interface, the database, and the import function (for those sources which are available) are all consistent in their processing and use the USMTF as the definition for legal field lengths and character sets. For those installations that still operate APS in a standalone manner the data input requirements can still represent an onerous burden for the system administration staff or whomever is tasked to maintain the data base. In a dynamic environment where significant changes to a TNL were required daily (i.e. a 500+ target scenario with weaponeering) the current setup screens and process would limit the effectiveness of APS due to the time and manpower requirements to input the data prior to the start of the planning session.

CONCLUSION

The APS IV&V effort represented an attempt to explore alternative concepts and methodologies in performance of an IV&V effort in an EA/RP environment. Classical IV&V techniques were deemed to be unresponsive to the dynamic nature and continually evolving baseline that is characteristic of the EA/RP environment. Alternative concepts and methodologies were examined and tailored to be responsive to the unique environment and challenges represented by a software development effort accomplished using an EA/RP methodology.

The APS IV&V effort specifically pursued the concepts of "Spotlighting", "Software Veracity", and extensive usage of a modern Software Engineering Environment to aid both the software designers and the IV&V engineers. The adoption of "Spotlighting" allowed IV&V personnel to focus on a specific area when it was crucial to the program and then essentially put that activity into a "maintenance" mode once the area had been adequately addressed. Software veracity was a technique established to ensure that the individual functional requirements were implemented completely and interacted with the rest of the system properly. A SEE was recommended and adopted by the program both to encourage modern software engineering practices and to allow a rapid analysis capability of design components as part of the verification process and to audit and accept each new delivered baseline.

The core ingredients to the APS IV&V effort being a positive factor towards the timely delivery of a quality APS product in the EA/RP environment was a combination of two factors: the cooperative working arrangement that evolved between the Air Force Program Office, the developer, and the IV&V contractor, and the development of an IV&V methodology that allowed the IV&V contractor to continually leverage the limited resources available.

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